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Short Communication

Establishing permanent monitoring plots of narrow endemic and threatened plants of Indonesia: a case study on *Dipterocarpus cinereus* Slooten (Dipterocarpaceae)

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Abstract

Permanent plots are commonly employed to record and monitor temporal changes in plant communities. In this study, we established a permanent plot to monitor the future population dynamics and regeneration of *Dipterocarpus cinereus* Slooten (Dipterocarpaceae), or Lagan bras, a critically endangered and narrowly endemic tree confined to the Mursala Island in Sumatera Utara Province, Indonesia. Using a quarter-hectare (50 × 50 m^2) plot, we collected initial data on the population structure of *D. cinereus* and the floristic composition of the tree community within the plot. Tree inventories were conducted by measuring all individual trees with a Diameter at Breast Height (DBH) of more than 5 cm. In the 0.25-hectare plot established, we recorded 261 trees, representing 76 species, 49 genera, and 32 families of flowering plants. There were seven individuals of *D. cinereus* in the plot, of which six were in mature stages with a DBH range of 79.5–38.8 cm. The results of our study can serve as baseline data for future monitoring programs of *D. cinereus* and the accompanying tree community. Furthermore, these results can support the implementation of existing long-term conservation strategies and action plans for the species.

Key words: Extinct species, IUCN Red List, *Keruing*, Lagan bras, Mursala Island, Sumatera

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Introduction

Permanent plots, defined as sampling plans where each tree is permanently marked, are commonly employed to monitor vegetation change (Poso 2006; Priyadi et al. 2006). The long-term data produced by regularly sampling permanent plots is the most precise measure to record and detect temporal changes in plant communities because the plots' fixed geographical location of the plots can prevent relocation bias, which is inherent in plant resurveys (Verheyen et

al. 2018; Damgaard 2019; de Bello et al. 2020). Due to this reason, permanent plots have been listed as one of the six most essential developments in vegetation sciences over the last three decades (Chytrý et al. 2019). Data collected from permanent plots offers many benefits, including understanding vegetation dynamics, assessing the stability of a plant community, tracking the successional trajectories, monitoring species' interactions over time, and providing detailed data on the population dynamic of high-conservation-importance species (Earle-Mundil 2010; Sperandii et al. 2022).

Plant species with restricted range are more sensitive to environmental changes and threats due to their restricted distribution and often low numbers of individuals, populations, or both (Işik 2011). Therefore, they represent an important group for conservation (Fenu et al. 2015; Huang et al. 2016; Orsenigo et al. 2018). To be effective, conservation actions require reliable information on the population dynamic and demographic status of the target species. Demographic studies will provide information on the critical phases of plant life history (Caswell 2000; de Kroon et al. 2000; Menges et al. 2016) and factors that drive fluctuations and population trends (Menges 2000; Sulis et al. 2018). These are important to determine best management practices and establish effective conservation programs (Schemske et al. 1994; Menges et al. 2016; Sulis et al. 2018). The use of permanent plots to study the long-term demographic status of narrow endemic and threatened plant species is still low, yet required for effective conservation (Menges 2000; Fréville et al. 2004; Jacquemyn et al. 2007).

Indonesia is a habitat for 1,070 threatened plant species, of which 600 (56%) are endemic (IUCN 2023). Currently, none of these endemic and threatened plant species have population dynamic and demographic information derived from long-term studies (e.g. Priyadi et al. 2006; Brearley et al. 2019). This condition will prevent the authority from determining the best management practices and establishing effective conservation programs.

Dipterocarpus cinereus Slooten, also known as Lagan bras by the locals, is a tree species of high-conservation-importance from the family Dipterocarpaceae. The species is endemic to Mursala Island in Sumatera Utara Province, Sumatera, Indonesia (Robiansyah et al. 2020a). In 1998, *D. cinereus* was listed as extinct on the IUCN Red List (Ashton 1998) before being rediscovered in 2013 (Kusuma et al. 2013). The species is currently threatened by habitat loss due to massive illegal logging and forest conversion and is assessed as Critically Endangered by the IUCN Red List (Robiansyah et al. 2020b). Despite its critical status recognised by the IUCN Red List, *D. cinereus* is not a protected plant species at the national level. However, the tree is included as one of Indonesia's 12 priority plant species for conservation (Hamidi et al. 2019). While ex-situ conservation of *D. cinereus* has been conducted (Susilowati et al. 2021), in-situ research and conservation actions that can support the species' survival are still lacking. In addition, information on population dynamics and demography of the species is absent (Hamidi et al. 2019).

In the present study, we established a permanent plot to monitor the future population dynamic, regeneration, and demography of *D. cinereus*. Initial data on the population structure of *D. cinereus* and the floristic tree community composition within the plot were presented. The results of our study can be used as baseline data for future monitoring programs of the species and accompanying tree community. The results can also support the implementation of the existing long-term

conservation strategies and action plans for *D. cinereus* that have been launched since 2019 (Hamidi et al. 2019). Furthermore, the study can become a conservation model for other Indonesian narrow endemic and threatened plant species.

Materials and methods

Study site

The permanent monitoring plot for *D. cinereus* was established on Mursala, a small island located on the west coast of the Sumatera Utara Province (Fig. 1). The island has an area of about 8,000 ha with hilly topography with the highest elevation of 500 m above sea level. The island's average air temperature and humidity are 26.7 °C and 75% (Rachmat et al. 2018), whereas the average precipitation is 12.96 mm/year (BPS Kabupaten Tapanuli Tengah 2017). Mursala Island is a habitat for at least 26 dipterocarp species, of which 76.9% are threatened with extinction (Robiansyah et al. 2020a). Therefore, Mursala Island is considered one of the dipterocarp biodiversity hotspots in Indonesia.

Tree inventories

In the present study, a quarter-hectare (50 × 50 m^2) permanent plot was established in the year 2022. The plot was located on a Northeast-facing sloped area (c. 17^0) with an elevation of 250 m above sea level. It was intentionally

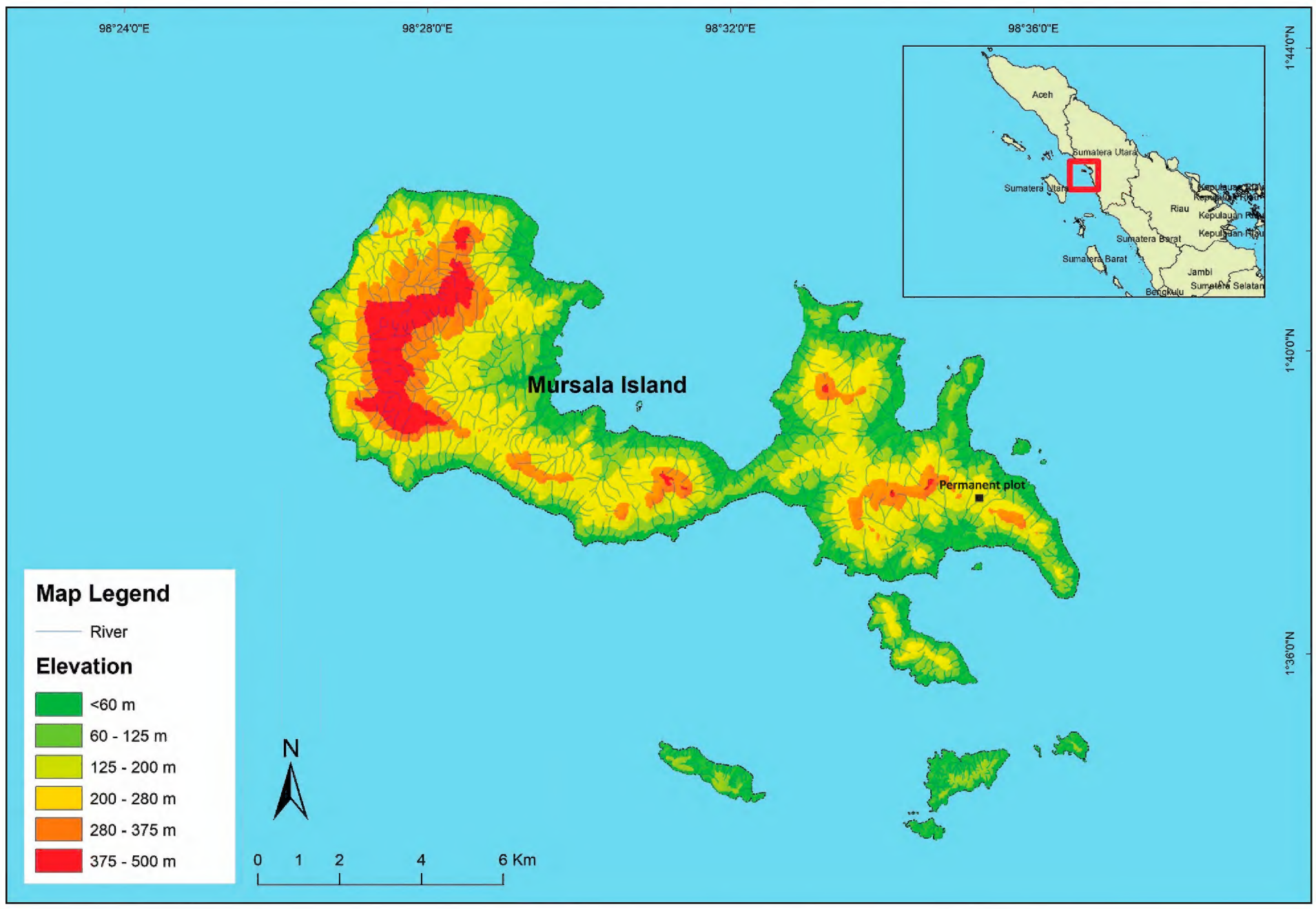

Figure 1. Location of the permanent monitoring plot for *Dipterocarpus cinereus* on Mursala Island.

established at a location with a high density of mature individuals and the wild regeneration of *D. cinereus*. One of the corners of the plot was georeferenced using a high-precision GPS receiver (Garmin GPSMAP 65s). To ensure the tree measurement process and plot orientation easier, we divided the plot into workable units of 25 subplots (10 × 10 m^2).

All trees with a Diameter at Breast Height (DBH) of more than 5 cm in the plot were measured at 1.3 m above ground. Each tree was given a unique identification number, and its position in the grid (x- and y-coordinates) was recorded. Herbarium vouchers were made for all measured trees for species identification purposes. Identification of tree species was based on relevant botanical and taxonomic literature pertinent to the Malesian flora and comparisons with digital herbarium images stored in the Global Biodiversity Information Facility (GBIF.org 2023) and Naturalis Biodiversity Center (https://bioportal.naturalis.nl/). Family and species names used in the study follow the Plants of the World Online (https://powo.science.kew.org/). We also checked the wood density of each species using the Tree Functional Attributes and Ecological Database developed by the World Agroforestry Center (http://db.worldagroforestry.org//wd). The wood density was then classified into the following groups (Melo et al. 1990): light (<0.5 g/cm^3), medium (0.5–0.72 g/cm^3), and heavy (>0.72 g/cm^3).

Data analysis

We constructed a species-area curve based on the cumulative value of each subplot. The diversity level of the plot was calculated using Shannon diversity and Simpson's evenness index (Magurran 2021). Both indexes were also calculated for trees with DBH ≥10 cm to make this study comparable to other permanent plot data in mainland Sumatera, which mainly used trees with at least 10 cm DBH. To identify important taxa in the plot, we calculated the Importance value index (IVI) for all families and species based on the sum of their relative frequency, density, and dominance (Mueller-Dombois and Ellenberg 1974). The stand structure of the plot was identified visually using DBH classes.

Results and discussion

Species diversity

According to previous studies (Robiansyah et al. 2020b, 2020a), 163 individuals of *D. cinereus* were recorded on Mursala Island. In the present study, we enumerated seven individuals of *D. cinereus* in the plot, of which six were mature (79.5–38.8 cm DBH), and one was immature with a trunk DBH of 8.9 cm. We also observed hundreds of seedlings (0.1–0.5 m height) of the species around the mature individuals (Fig. 2). Therefore, our plot represented one of the sites on the island with a high density of *D. cinereus*.

In the 0.25 ha plot, we recorded 261 trees, representing 76 species, 49 genera, and 32 families of flowering plants (Suppl. material 1). Of these 76 species, 63 were identified down to the specific level, nine taxa to the generic level, three taxa to the family level, and one was unidentified. The Shannon diversity index of the plot was 3.87, which indicated that the plot has a high plant species diversity. In general, most ecological data shows the range of the Shannon diversity

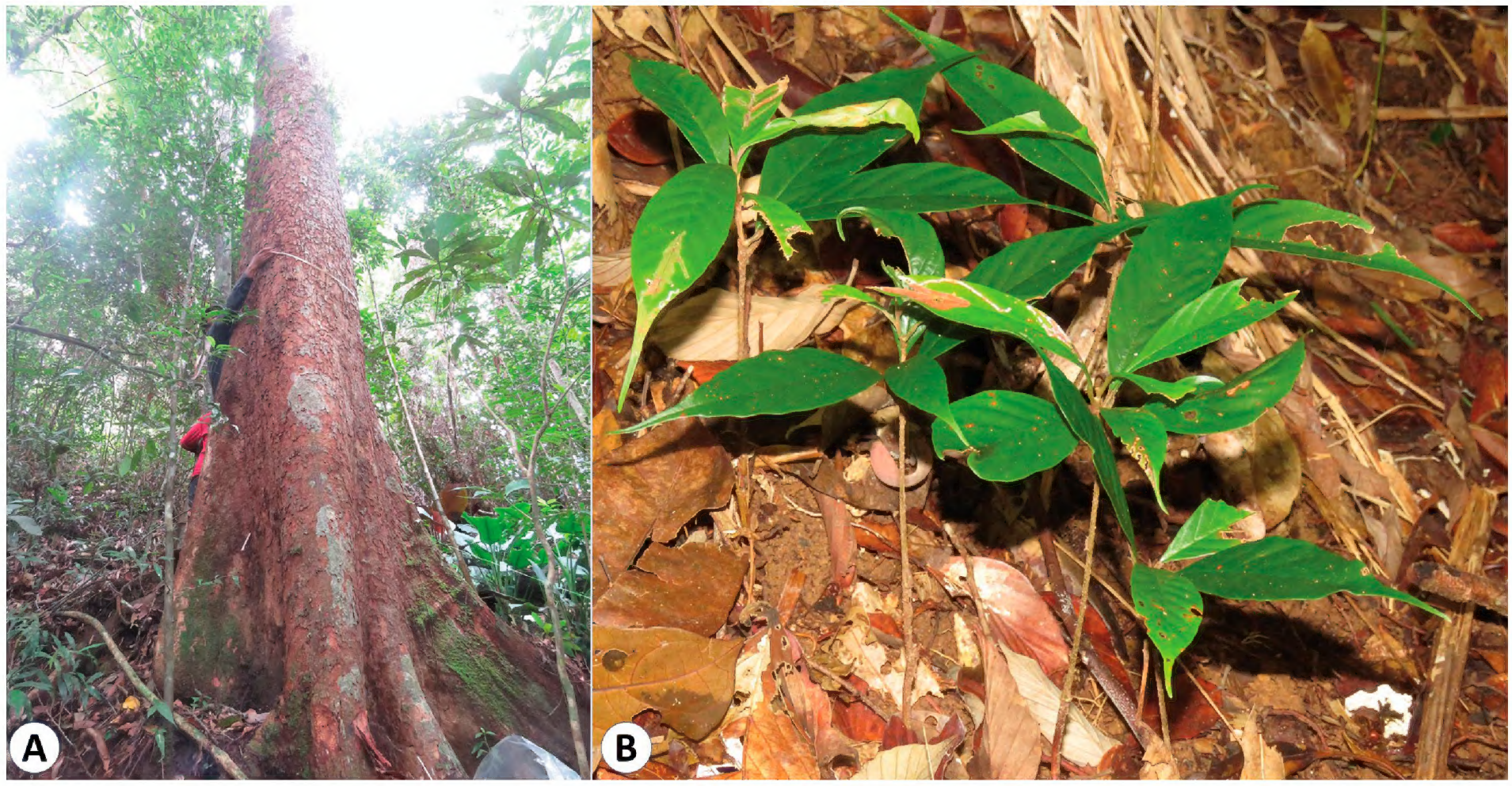

Figure 2. A mature individual (**A**) and seedlings (**B**) of *Dipterocarpus cinereus* Slooten found in the permanent plot.

index of 1.5–3.5 and only rarely surpasses 4.5 (Gaines et al. 1999). The Simpson's evenness index of the plot is 0.97, which indicates that the species within the plot are present in relatively equal abundance (Beisel et al. 2003).

The species-area curve is constructed to depict species diversity in relation to the increasing size of the area (Mueller-Dombois and Ellenberg 1974), and it can be used to evaluate species diversity patterns in different types of forests (Ashton 1965). Following Scheiner (2003), the species-area curve in the present study could be classified as a type II curve since it was constructed based on quadrats arrayed in a contiguous grid. This type of curve usually forms a smoothly rising pattern. Indeed, the species-area curve in the present study (Fig. 3) showed a steady increment, and at a quarter-hectare, there is no sign of levelling off. It indicated that the forest has a relatively high species diversity, as shown by the species number 51 and Shannon diversity index of 3.87.

Most permanent plots in Sumatera use trees with at least 10 cm DBH. Therefore, to make this study comparable, we presented the subset data using trees with DBH of ≥10 cm (Table 1). The permanent plot in this study had a lower tree density (516 individuals/ha) than the studies in Gunung Leuser National Park (582 individuals/ha; Basyuni et al. 2019), Bukit Duabelas National Park (540 individuals/ha; Anas et al. 2021), and Batang Gadis National Park (583 individuals/ha; (Kartawinata et al. 2004). The density, however, was higher compared to another study in Gunung Leuser National Park (470 individuals/ha; Basyuni et al. 2019) and Bukit Duabelas National Park (414 individuals/ha; Rahmah et al. 2016). According to Kartawinata (1990), the range of tree density (DBH ≥10 cm) in Malesia's lowland rainforest is 350–800 trees/ha.

In terms of species number, our plot had the lowest species diversity (51 species) compared to other studies in mainland Sumatera. However, this was caused by the small area used in the present study. Using the trendline equation of the log-log species-area curve (Fig. 3), we estimated that the species number in the present study would reach up to 75 and 116 if the plot size is

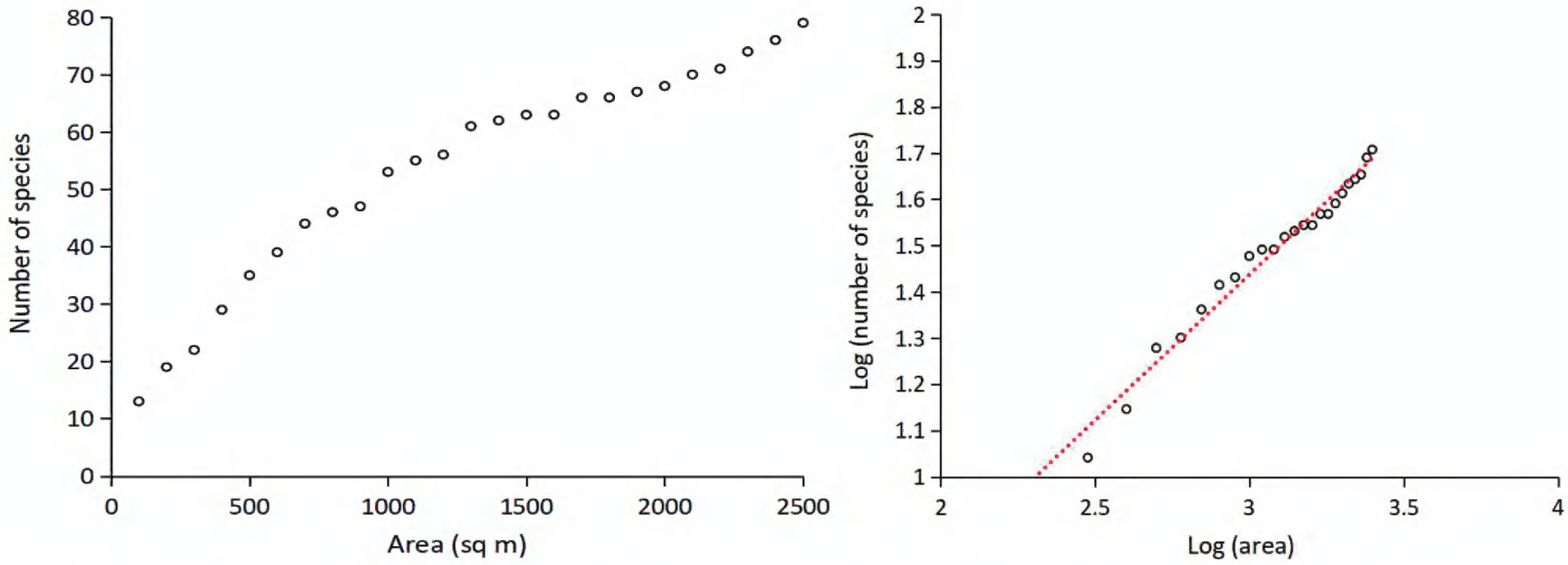

Figure 3. A species-area curve in a 0.25 ha forest plot on Mursala Island, Indonesia. The left curve uses arithmetic axes for trees with a Diameter at Breast Height (DBH) ≥5 cm (left), whereas the right curve uses log-log axes for DBH ≥10 cm. The red line is a linear trendline with y=0.6313x-0.4571 (R^2=0.99).

Table 1. The tree (diameter at breast height ≥10 cm) structure and composition of the present study and comparison with other studies on mainland Sumatera.

Variable	This study (2022)	Basyuni et al. (2019)		Rahmah et al. (2016)	Anas et al. (2021)	Kartawinata et al. (2004)
Location	Mursala Island	Gunung Leuser National Park A	Gunung Leuser National Park B	Bukit Duabelas National Park A	Bukit Duabelas National Park B	Batang Gadis National Park
Area (ha)	0.25	0.5	0.5	1	1	1
Altitude (m)	250	75–100	75–100	200–300	265–327	650
Tree number	129	291	235	414	540	583
Species number	51	100	88	113	89	184

increased to 0.5 and 1 ha, respectively. Following this extrapolation, the diversity is now higher than that of Bukit Duabelas National Park (Anas et al. 2021; Rahmah et al. 2016) but still lower than Gunung Leuser National Park (Basyuni et al. 2019) and Batang Gadis National Park (Kartawinata et al. 2004). Whitmore (1986) pointed out that the differences in species diversity in lowland forests are strongly related to the variations of topography, terrain, and degree of natural disturbance. In addition, according to the island biogeography theory, the plant diversity on a small island is affected by its size and distance to the main island (Guo 2015).

Important taxa

As the target species, *D. cinereus* had the highest IVI value (26.74) in the plot (Suppl. material 1). It was closely followed by *Shorea multiflora* (Burck) Symington (22.06), *Teijsmanniodendron holophyllum* (Baker) Kosterm. (15.87), *Shorea ovat*a Dyer ex Brandis (13.77), *Pentace sumatrana* Kosterm. (12.75), and *Vatica venulosa* subsp. *simalurensis* (Slooten) P.S.Ashton (12.31). A previous study by Robiansyah et al. (2020a, b) showed that *S. multiflora* was widely distributed on Mursala Island and had an estimated density of 21.72 ± 10.96 individuals/ha. This species is also commonly found in lowland forests of Peninsular Malaysia, Sumatera, and Borneo (Ashton 1982; POWO

2023) and is assessed as Least Concern according to the IUCN Red List (Barstow 2018).

At the family level, the highest number of species found was in Dipterocarpaceae (seven species), followed by Myristicaceae (six species), Myrtaceae (six species), and Ebenaceae (six species). Furthermore, Dipterocarpaceae had the highest IVI value (94.38), followed by Lamiaceae (19.84), Myrtaceae (17.81), Clusiaceae (17.66), and Anacardiaceae (15.14). There were 16 families (50%) represented by a single species. Of the 26 Dipterocarpaceae species recorded for the island, only seven were recorded from the plot (Robiansyah et al. 2020a). In the lowland forests of the mainland of Sumatera, Dipterocarpaceae is also reported to be one of the most dominant families in terms of the number of species (e.g. Rahmah et al. 2016; Basyuni et al. 2019).

Stand structure and wood density

The stand structure of a forest can be represented horizontally by the diameter class distribution (Purwaningsih and Yusuf 2005). In the present study, the diameter class distribution curve showed an inverted J-shaped (Fig. 4). This type of curve is commonly found in tropical forests and is characterized by the dominance of trees with DBH less than 20 cm, reflecting the general characteristics of dynamic tropical forests (Richards 1973). A total of 205 trees with DBH ≤20 cm were located in the present plot, which amounted to more than 78% of the total trees. All trees with DBH >65 cm were from the family Dipterocarpaceae and consisted of three species, i.e. *D. cinereus*, *S. multiflora*, and *S. ovata*. The dominance of Dipterocarpaceae at the upper end of the diameter class is also observed in Bukit Duabelas National Park (Anas et al. 2021) and Batang Gadis National Park (Kartawinata et al. 2004).

Wood density is one of the reliable predictors of the successional stage of a forest (Slik 2005). The domination of trees with medium to heavy wood density indicates that a forest is in a later successional stage. In contrast, a higher proportion of trees with low wood density means they are in an early successional stage (Slik et al. 2008). In our study site, the tree community showed a characteristic of a mature forest where there were more trees with medium (59.6%) and heavy wood density (32.7%) compared to those with light wood density (7.7%) (Fig. 4). To cope with understory conditions, trees in old-growth, mature forests develop conservative strategies: low growth rate and high wood density (Chao et al. 2008; Chave et al. 2009; Poorter et al. 2021).

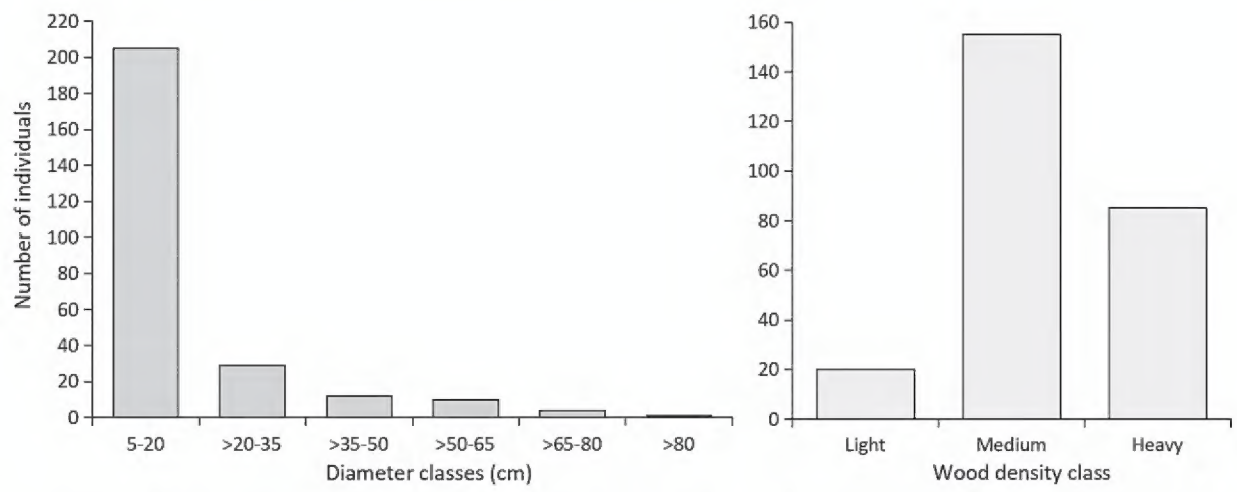

Figure 4. The stand structure of a 0.25 ha forest plot on Mursala Island, Indonesia. The structure is based on the diameter at breast height (dbh) class (left) and wood density classification (Melo et al. 1990; right).

Comparison with other similar studies

Our study was the first to use permanent plots to examine narrow endemic and threatened plant species in Indonesia. Previous studies utilizing permanent plots in Indonesia primarily focused on monitoring above-ground carbon stock, forest recovery, and tree species richness (Brearley et al. 2019). Studies similar to ours have been conducted in Vietnam (Chien et al. 2008), Brazil (Sant'Anna et al. 2013), the Netherlands (Jacquemyn et al. 2007), and France (Fréville et al. 2004), where permanent plots were used to monitor the population demographics of threatened plant species. However, those studies concentrated on the target species and did not assess the accompanying tree species community. We believe that our method, by including measurements of the accompanying tree community, will provide more comprehensive data and can be used to monitor various factors related to the target species and the forest ecosystem.

Conclusion

Our permanent monitoring plot represented one of the sites on Mursala Island with a high density of *D. cinereus*. The tree vegetation composition and structure in the plot showed a typical mature lowland forest with a high density of trees from medium to high wood density and an inverted J-shaped diameter class distribution. The results of our study can be used as baseline data for future monitoring programs of *D. cinereus* and the accompanying tree community. The results can also support the implementation of the existing long-term conservation strategies and action plans for the species. These include supporting the designation of Mursala Island as a protected area, listing *D. cinereus* as a protected plant species, and attracting relevant stakeholders to actively engage in the conservation of *D. cinereus* and its habitat. Finally, our study can become a model for conserving other Indonesian narrow endemic and threatened plant species.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Conceptualization: AS, EMDR, EP, AA, IR, HHR, AH. Data curation: IS, IR, MNZ, EP, AH. Formal analysis: IS, IR, EP. Funding acquisition: IR. Investigation: IR, IS, EP, AH, MNZ. Methodology: HHR, IR, EP, AH, AS, AA, EMDR. Project administration: MNZ, EMDR, IS, AA, HHR, AS, AH, IR, EP. Supervision: IR. Validation: IR, AH. Visualization: MNZ, IR, EP, IS. Writing - original draft: IR. Writing - review and editing: AH, HHR, EP, AA, EMDR, IS, MNZ, IR, AS.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

List of plant species found in the study plot

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Data type: xlsx

Explanation note: Importance value index (IVI) and wood density of tree species in a 0.25 ha plot of forest on Mursala Island, Indonesia. IVI is calculated based on the relative density (RD), frequency (RF) and dominance (RDm) of each family and species.

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